LIFE HISTORIES OF THE PROTOZOA.

BY A. S. PACKARD, JR.

THE design of the present series of papers is to give the results of studies by different authors on the development of the typical forms of animals, beginning with the lowest and ending with man.

I. THE MONERA.

Structure and Habits. Hæckel, in 1868, applied to this group of organisms, which are doubtfully referred to the animal kingdom, the term *Monera* (from μονήρης, simple) in allusion to the extreme simplicity of their structure. "Their whole body," he remarks, "in a fully developed and freely moving condition, consists of an entirely homogeneous and structureless substance, a living particle of albumen, capable of nourishment and reproduction." They differ from the Amœbæ, hitherto supposed to be as simple as any organism, in the want of a nucleus and of contractile vesicles. Moreover, they (as in Protamœba) differ from the Rhizopodous Amœba in being entirely homogeneous in structure, there being, as Hæckel observes, "no apparent difference between a more tenacious outer and a softer inner sarcode mass," as is "perceptible in most, perhaps in all, true Amœbæ."

The motions of these Moners are effected by contraction of the homogeneous substance of the body, and by the irregular protrusion of portions of the body, forming either simple processes (pseudopodia) or a net-work of gelatinous threads. The food is taken in after the manner of the Amœba, the diatom, desmid or some protozoan being surrounded by the pseudopodia and gradually enfolded by the extremely extensible body mass. Hæckel says that reproduction is effected solely in a non-sexual manner. "Often, but not always, the freely moving condition alternates with a state of rest, during which the body surrounds itself with an excreted structureless covering," becoming in fact encysted.

The Monera are divided into two groups:

1. *Gymnomonera*, comprising the genera *Bathybius*, *Protobathybius*, *Protamœba*, *Protogenes* and *Myxodictyum*, which do not become encysted and consequently protected by a case.

2. *Lepomonera*, which become encysted and protected by a case, as in the genera *Protomonas*, *Protomyxa*, *Vampyrella* and *Myxastrum*.

The simplest form of all is Protamœba, which is a simple mass of protoplasm without vacuoles (little cavities), which protrudes simple processes (pseudopodia) not ramifying or forming a network. Protogenes differs in protruding ramifying and anastomosing gelatinous threads, while Myxodictyum, the most complicated form, is made up of several simple Actinophrys-like bodies, whose pseudopodia branch out and interlace, forming a net.

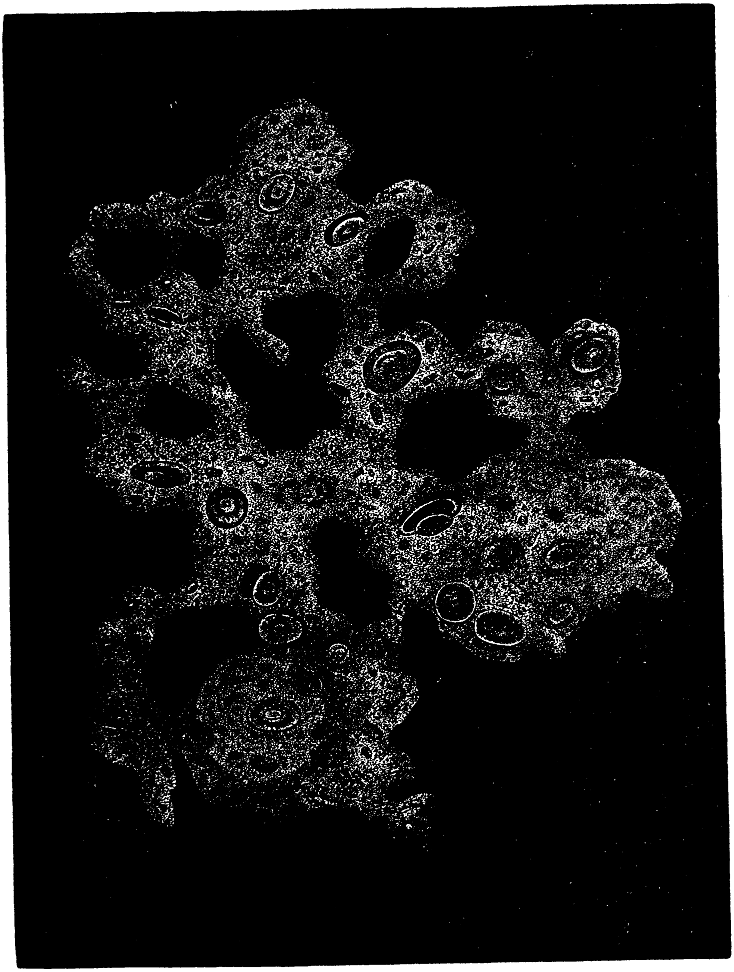
The simplest form of life known to us is Bathybius, a mass of albuminous jelly. If the theory of spontaneous generation should ever prove true we could imagine that the first living form would be like this organism, a mass of jelly, utterly structureless, and yet capable of motion (irritability), of taking food and digesting it, and of reproducing its species, and thus having an individuality.

Bathybius is consequently the most interesting organism (should it be proved to be such,) known except man. It cannot be said to be distinctively either animal or plant, though it has been studied chiefly by zoologists, and intergrades with the higher Moners, which seem to pass by the sum of their characters into the Amœbæ and higher Rhizopods rather than into the Protophytes. But in the Moners we find a group of uncertain forms from which the plant and animal kingdoms diverge, and from which, consequently, they may have taken their origin. The Moners stand in the same relation to the whole world of organized beings that the egg does to the animal kingdom. All animals exist first in the form of nucleated cells, while the primitive form of plants and animals collectively, is a simple non-nucleated mass of protoplasm like Bathybius, and for these forms, neither distinctively plant nor animal, Hæckel's term Protista is a convenient one for *provisional* use.

Bathybius was first discovered by Prof. Wyville Thompson in 1869 in dredging at a depth of 2435 fathoms at the mouth of the Bay of Biscay. He describes it as a "soft, gelatinous, organic matter, enough to give a slight viscosity to the mud of the surface layer." Thompson also adds that if a "little of the mud in which this viscid condition is most marked be placed in a drop of sea water under the microscope, we can usually see, after a time, an irregular net-work of matter resembling white of eggs, distin-

guishable by its maintaining its outline and not mixing with the water. This net-work may gradually alter in form, and entangled granules and foreign bodies change their relative positions." To

Fig. 126.



Bathybius.

this low Moner Huxley has given the name of *Bathybius Hœckelii* (Fig. 126, with coccoliths embedded in the protoplasm, from Thompson's "Depths of the Sea"). This Moner, adds Thompson, "whether it be continuous in one vast sheet, or broken up

into circumscribed individual particles, appears to extend over a large part of the bed of the ocean." It should be stated that Thompson and others do not believe that Bathybius is really an organic being. Bathybius has been discovered at a depth of from fifty fathoms downward in the Adriatic Sea, by Oscar Schmidt. The Bathybius mud was detected by its yellowish-gray color and its characteristic greasy nature.

Under the name of Protobathybius Dr. Bessels mentions a Moner allied to Bathybius, which is a non-nucleated mass of protoplasm. It was discovered at a depth of ninety fathoms, mud, in Polaris Bay, Northern Greenland.

The *Protogenes primordialis* of Hæckel is a simple, shapeless mass of protoplasm, without vacuoles, but with over 1000 very fine pseudopodia, with numerous ramifications and anastomoses. The largest specimens are ·04 inch in diameter. It is a marine form, found at Nice. It reproduces by fission.

Myxodictyum is made up of several individuals, each one of which is like Protogenes, but with fewer pseudopods. *M. sociale* Hæckel, in the single specimen observed, formed a mass nearly an inch and a half in diameter, and was discovered in the Straits of Gibraltar.

Protomonas amyli (Ckski.) is a fresh-water, monad-like form, found by Cienkowski in Germany and Russia, and is from ·08 to ·20 inch in diameter. *Protomyxa aurantiaca* Hæckel has vacuoles in its simple, shapeless, orange-red body, and in the encysted condition is a globular jelly-like mass over half an inch in diameter. It occurred on empty shells of *Spirula Peronii*, floating about on the open sea, and driven in on the coast of one of the Canary Islands. *Vampyrella*, as its name implies, is a jelly-like mass, which according to Cienkowski bores into the cells of confervæ and other fresh-water algæ, and sucks out their contents. Another species, *V. vorax*, engulfs diatoms, desmids and infusoria, drawing them into the interior of its body.

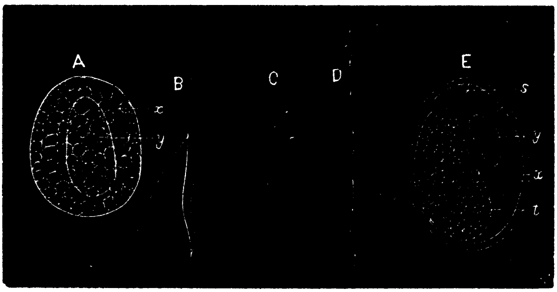
The highest form among the Moners is *Myxastrum radians* of Hæckel, which forms a radiating ball of jelly of tough consistence from ·12 to ·20 inch in diameter. It has very tough, stiff pseudopods. In the encysted condition it is nearly half an inch in diameter, and occurred on the beach of one of the Canary Islands.

Development. In Protamœba and Protogenes, Hæckel tells us we find the simplest possible mode of reproduction. They mul-

tiply by merely dividing into two portions, each part becoming an individual.

The distinguished Russian microscopist Cienkowski has given an account of the mode of development of *Protomonas amyli*, which corresponds to that of the lowest algæ, such as Protococcus (see Clark's Mind in Nature, p. 136, Figs. 73–79); both reproduce by spores; those of the animal Protomonas may be called "zoospores." Fig. 127 (copied from Cienkowski) represents at A this moner during the formation of the zoospores; B, a zoospore hatched out; C, D (A — D × 350 diameters), the Amœba-like form it afterwards assumes. From these stages Cienkowski traced it to the encysted, or resting stage, E; (*y*, food; *s*, a projection inwards of the cell-wall; *x*, moner-cyst × 450). This form lives in putrefying Nitellæ. It should be observed that the

Fig. 127.



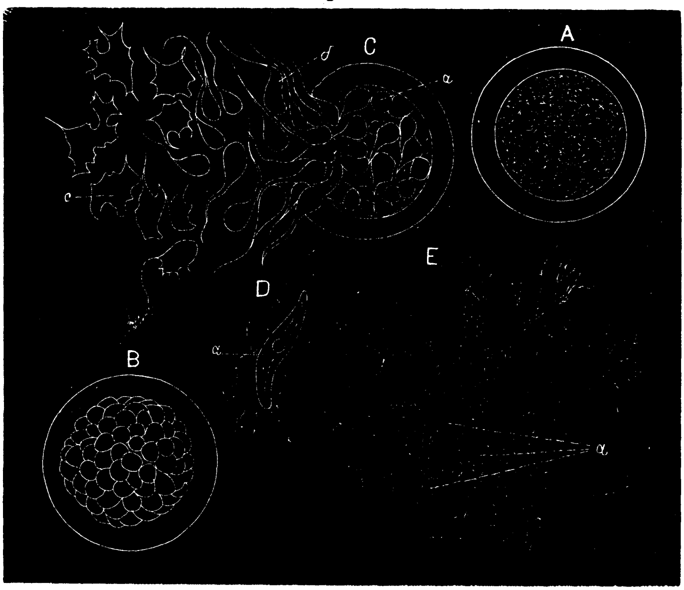
Development of Protomonas.

cyst of this Protomonas, as in the true Monads studied by Cienkowski, is composed of cellulose, while the granular contents become colored with chlorophyll. In these respects they are *plants*, but it should be remembered that cellulose is said to occur in the mantle of the Tunicates and various parts of Articulates and Vertebrates, while chlorophyll occurs in the Infusoria and Hydra.

The course of development of Protomyxa has been observed by Hæckel. The orange-red contents of the ball or cyst (Fig. 128, A) of this moner, divided, after it had retracted itself from the hyaline capsular wall, into several hundred small, round, thoroughly structureless, naked balls (Fig. 128, B). This process Hæckel regards rather as a "germ formation," than a process of division or gemmation. These small globular masses of protoplasm (*a*) are each drawn out into a long tail (*b*), and issue from

the cyst as "swarm-spores" (zoospores, Fig. 128, C *a*, *b*, *c*). These zoospores then assume an amœba-form. These unite by twos or threes, or more, and form a new individual as at D, where two amœba-like germs unite themselves by their anastomosing pseudopods and draw themselves over a Diatom (*a*), meet in the middle, and unite into one individual moner. Fig. 128, E, represents a fully grown *P. aurantiaca* after having had a liberal diet of shelled Infusoria (E, *a*). From the central sarcode body the very strong, branching, tree-like pseudopods radiate, their outer

Fig. 128.



Development of Protomyxa.

anastomoses forming numerous crescent-shaped meshes. The vacuoles extend into the larger pseudopods; they first appear in the Amœba stage after they begin to take food.

This adult, Amœba-like form becomes encysted in the manner thus described by Hæckel. "To complete the natural history of the Protomyxa, it still remained only to observe the encysting of the adult form, the transition from the free moving plasmodia to the stationary red balls which had attached themselves to the Spirula shells near the latter. I succeeded in establishing this also. Two of the largest of the best fed plasmodia, which con-

tained very numerous vacuoli, and which had formed a very extended sarcode net, with many branches and anastomoses, after some time began to slacken their extremely rapid currents, and to simplify their pseudopods. The silicious shells of the many diatoms which had been absorbed were rejected, and the branches and twigs of the pseudopods were successively retracted. At last they drew back the main stems, which had everywhere become simple, into the central plasma-body, and the entirely homogeneous sarcode body took the form of an irregular lump, and finally rounded itself into a regular ball.

"Now commenced the separation of the covering of the cyst, in which the sharply defined single outline of the orange-red plasma-balls passed into a perceptible, though certainly fine, double outline. A second, and then a third, concentric boundary line soon followed this, and then the proper concentric hyaline cyst-covering appeared somewhat quickly (in the course of a day); its layers corresponded with the above stated breaks of the separated gelatinous skin. At first a quantity of vacuoli were still perceptible in the plasma during the encysting process, which appeared and disappeared here and there, but visibly decreased in numbers; and after the complete development of the cyst covering, no vacuoli could be any longer perceived in the orange-red plasma, now interspersed with numerous granules. The encysted plasma-ball was now no longer to be distinguished from those red balls whose transition to the mass of sporules I have above described. Thus was the cycle of the generation of the Protomyxa completed, and the course of its simple and remarkable life history established."

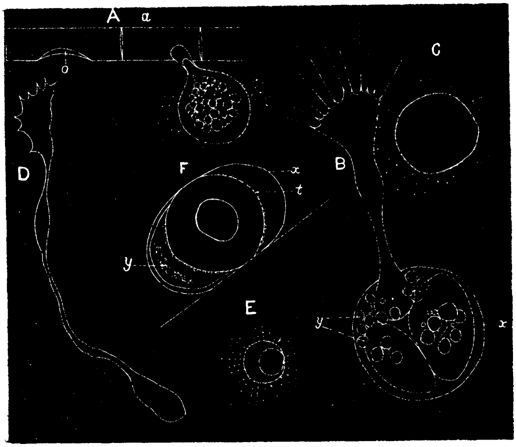
The phases may be thus summed up:—

1. The free swimming flagellate state (sporule or zoospore).
2. The creeping Amœba state.
3. The reticulated Rhizopod state.
4. The encysted state.

Somewhat similar is the development of *Vampyrella spirogyræ*, which penetrates into the cells of the fresh-water plant Spirogyra, and absorbs its protoplasm. Fig. 129, A, represents the adult, with its radiating pseudopods, and a large one in the act of boring into the walls of the plant. It then withdraws its pseudopodia, and assumes what Cienkowski calls the cell-state. During this period it is surrounded by a delicate membrane. The granular

contents divide into three portions, each of which becomes an Amœba-like being (Fig. 129, B, showing one creeping out of the cell, *x*. C, D, E, the Amœba-like stage). Finally one of these

Fig. 129.



Development of Vampyrella.

Amœba-like forms becomes encysted (Fig. 129, F, *y*, the food-granules; *t*, cell-wall of the cyst). To sum up the life-history of Vampyrella as observed by Cienkowski, we have:—

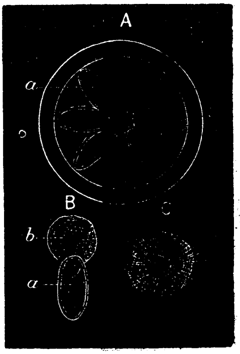
1. An Amœba-stage.
2. A cell-stage.
3. A second Amœba-stage.
4. An encysted stage.

So exactly does this mode of development parallel that of *Colpodella pugnax* described by Cienkowski, who regards it as a flagellate infusorian allied to Monas, that we doubt the naturalness of Hæckel's division of Monera. Colpodella and in fact Protomonas differ from the Monads (Flagellata) simply in having no nucleus. Whether this may not be found on further observation, or whether its absence or presence is so important as Hæckel thinks, future observation will show. We are now inclined to regard the Monera as a somewhat artificial group. It should be noticed that none of the other Moners have a "cell-state," but the Amœba-like organism becomes encysted at once after becoming fully fed.

The development of *Myxastrum radians* of Hæckel is much like

that of Protomyxa, but differs in some important respects. The cyst becomes filled with numerous conical portions, whose points rest towards the centre of the ball, while their rounded bases produce a mulberry-shaped outline externally. In the next stage these cone-shaped divisions have assumed a spindle shape, and each separate spore has developed a silicious covering (Fig. 130, A, a). When the spindle-shaped spore has been set free the protoplasmic contents (b) slip out of the silicious shell (Fig. 130, B, a), and assume an Amœba form, with numerous radial pseudopods (Fig. 130, C), which in the fully formed Moner become as long as the diameter of the body.

Fig. 130.



Development of Myxastrum.

With the facts that have been presented, the question arises whether these moners are animals or vegetables. Structurally, and in their mode of development, the Monera would seem not to differ essentially from the lowest plants, such as the Myxomycetes and lowest Algæ; but physiologically, or *in what they do*, they differ, as H. J. Clark (Mind in Nature, p. 151, 156) says of Amœba, in taking in living organisms entire, digesting their protoplasm and rejecting the silicious coverings of the diatoms or infusoria they have swallowed. The plants of correspondingly low organization on the contrary absorb only the elements in an unorganized state.

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II. THE GREGARINIDA.

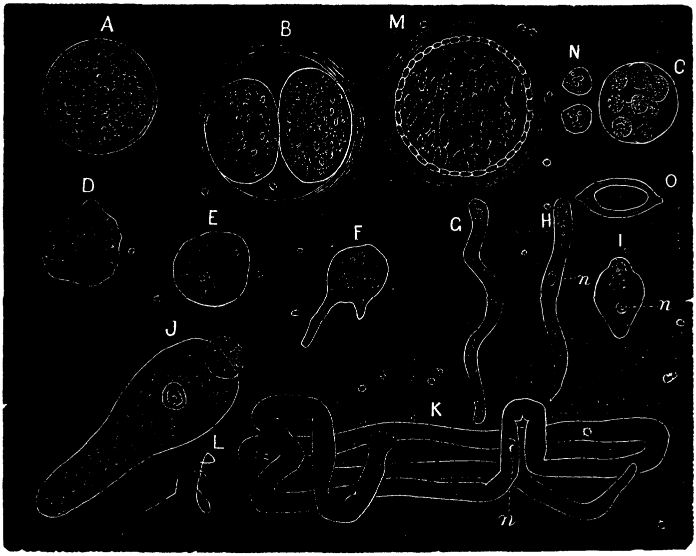
Structure and Habits. First discovered by Dufour, these parasitic protozoans, with an organ, *i. e.*, a nucleus, were considered as the lowest animals until the discovery by Hæckel of the still simpler Monera. It is now known that they pass through the Moner-state and attain a true Amœba condition, having an outer, clear,

muscular, and an inner, medullary or granular, layer, which are more distinct than in the Amœbæ, and also a nucleus. In form they are more or less worm-like. They are parasitic, living in many types of animals, especially the insects and worms, and vary greatly in form. The largest species known is *Gregarina gigantea* (Fig. 131 after Van Beneden), which lives in the intestinal canal of the European lobster. It is worm-like, remarkably slender, being ·64 inch in length. It is, in fact, the largest one-celled animal known, and in size may be compared with the cells of some vegetables; in the animal kingdom it is only surpassed by the eggs of birds, which are really cells. In this organism an external, structureless, perfectly transparent membrane, with a double contour, can be very clearly distinguished. It represents the cell wall of other cells. Beneath this outer wall is a continuous layer of contractile substance, by which these animals retain their form, not changing as in the Amœba. It was first discovered in 1852, by Prof. J. Leidy. He showed that there existed under the cuticular, structureless membrane, a so-called muscular layer, which in contracting becomes longitudinally folded, so as to produce a marked striation. Van Beneden adds that in "the immense Gregarina of the lobster I have assured myself of the presence of, under the cuticle, a true system of muscular fibrillæ, comparable to those of the Infusoria." From this fact he places these animals above the Amœbæ, which move by the simple contractility of their sarcode or protoplasm, a property of all animal and vegetable protoplasm generally. He therefore opposes the opinion of Hæckel that the Gregarina is an Amœba, degraded by its parasitic life.

The internal granular matter of the Gregarina is extremely mobile, like protoplasm generally. "The whole cavity of the body is filled," says Van Beneden, "with a granular matter formed by a viscid liquid, which is perfectly transparent. This holds in suspension fine granulations of a rounded form, which are formed by a highly refractive and slightly yellow matter." In this granular matter the nucleus is suspended. The nucleus is surrounded by a membrane, and the cavity of the vesicle is filled by a homogeneous, colorless and transparent liquid. This nucleus contains an inner vesicle, or nucleolus, which has the singular feature of spontaneously appearing and disappearing in a very short space of time. "If one of these Gregarinæ of moderate size is observed, the nucleus is seen at first provided with a single nucle-

olus, presenting some seconds later a great number of little refracting corpuscles, of very variable dimensions, which are also nucleoli. Some of these enlarge considerably, whilst the primitive nucleolus diminishes in volume little by little, finally disappearing. The number of nucleoli varies at every instant." These novel observations are considered of great importance by Van Beneden as showing that the nucleolus of the Gregarina, and consequently the nucleoli of cells generally are sometimes, if not always, devoid of a membrane. And he draws the inference "that the nucleus of a cell is not necessarily a vesicle, and that

Fig. 131.



Development of Gregarina.

contrary to the generally received opinion, a nucleus of a cell may be equally devoid of membrane," though we may add that he saw it in the Gregarina of the lobster. Van Beneden distinguishes three kinds of motions in the Gregarinæ. 1. They present a very slow movement of translation, in a straight line and without the possibility of distinguishing any contraction of the walls of the body which could be considered as the cause of the movement. It seems impossible to account for this kind of motion. 2. The next kind of movement consists in the lateral displacement of every part, taking place suddenly and often very violently, from a

more or less considerable part of its body. Then the posterior part of the body may be often seen to throw itself out laterally by a brusque and instantaneous movement, forming an angle with the anterior part. 3. Owing to the contractions of the body the granules within the body move about.

Development. The history of Gregarina has been worked out by Siebold, Stein, Lieberkuhn, and more recently by E. Van Beneden. The course of development is as follows: the worm-like adult, *G. gigantea* (Fig. 131, K, *n* nucleus, L, two individuals natural size), which is common in lobsters on the European coast in May, June and August, becomes encysted in September in the walls of the rectum of the lobster, the cysts (Fig. 131, A) appearing like "little white grains of the size of the head of a small pin." When thus encysted the animal loses its nucleus, and the granular contents of the cyst divide into two masses (B), like the beginning of the segmentation of the yolk of the higher animals. The next step is not figured by Van Beneden, and we therefore introduce some figures from Lieberkuhn which show how the granular mass breaks up into zoospores (called by authors "pseudo-navicellæ," and by Lieberkuhn "psorosperms") with hard shells. After the disappearance of the nucleus and vesicle, and when the encysted portion has become a homogeneous granular mass, this mass divides into a number of rounded balls (Fig. 131, C). These balls consist of fine granules, which are the zoospores in their first stage (Fig. 131, N). They then become spindle-shaped (O), and fill the cyst (Fig. 131, M), the balls having meanwhile disappeared. From these zoospores are expelled Amœba-like masses of albumen (D, E) which, as Van Beneden remarks, exactly resemble the Protamœba already described. This moner-like being, without a nucleus, is the young Gregarina.

But soon the Amœba characters arise. The moner-like young (Fig. 131, D, E) now undergoes a further change. Its outer portion becomes a thick layer of a brilliant, perfectly homogeneous protoplasm, entirely free from granules, which surrounds the central granular contents of the cytode (Hæckel) or non-nucleated cell. This is the Amœba stage of the young Gregarina, the body, as in the Amœba, consisting of a clear cortical and granular medullary or central portion.

The next step is the appearance of two arm-like projections (Fig. 131, F), comparable to the pseudopods of an Amœba. One

of these arms elongates, and separating forms a perfect Gregarina. Soon afterwards the other arm elongates, absorbs the moner-like mass and also becomes a perfect Gregarina. This elongated stage is called a Pseudofilaria (Fig. 131, G). No nucleus has yet appeared. In the next stage (Fig. 131, H, *n*; nucleus) the body is shorter and broader, and the nucleus appears, while a number of granules collect at one end, indicating a head. After this the body shortens a little more (I, J), and then attains the elongated, worm-like form of the adult Gregarina (K). Van Beneden thus sums up the phases of growth:—

1. The Moner phase.
2. The generating Cytode phase.
3. The Pseudo-filaria phase.
4. The Protoplast* (adult Gregarina).
5. The encysted Gregarina.
6. The sporogony phase (producing zoospores).

It seems evident that the mode of development of the Gregarina in part corresponds quite closely with the mode of growth of the Moners; for example, it becomes encysted, *i. e.*, sexually mature, produces zoospores (pseudonavicellæ), and from these zoospores issues the young or larval form of the Gregarina. These zoospores abound in damp places and are devoured by insects and worms. After they are swallowed the shells burst and the Amœba-like young are set free in the body of their host.

It will be seen that there is here a total absence of sexual reproduction. The Moner-stage arises by self-division of the contents of the cyst, a process analogous to the segmentation of the yolk of eggs; and the Pseudofilariæ arise by self-division of the young in the Moner-stage, *i. e.*, by a budding process.

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*The Gregarinæ and Amœbæ constitute Hæckel's group of *Protoplasta*.

III. THE RHIZOPODA.

Structure and Habits. We have almost anticipated a definition of the Rhizopoda, of which the Amœba, or Protean animalcule, is the simplest form, by our frequent references to the "Amœba-form" or "Amœba-like" stages in the Moners and Gregarinas. The Amœba is the starting point, the unit of the nucleated Protozoa, the primitive, ancestral form to which the members of the subkingdom may be reduced. Until the Monera were discovered the Amœba was regarded as the lowest possible animal.

With the form of the Monera, a shapeless mass of protoplasm, changing each instant, throwing out threads or larger protrusions of the body, the Amœba possesses a distinct organ, the nucleus, and its body mass is divided into a clear cortical and a medullary granular mass; the outer highly contractile, the inner granular portion acting virtually as a stock of food. These granules, like the grains of chlorophyll in vegetable cells and Diatoms and Desmids, circulate in regular fixed currents, according to J. H. Clark. (See Fig. 132, after Clark; the usual form of *Amœba diffluens* Ehrenberg, magnified 100 diameters; the arrows indicate the course of the circulating food. The head end is knobbed, and within free from granules.) We have then in Amœba:—

Fig. 132.

Amœba.

1. A nucleus, probably representing the nucleus and ovary of the Infusoria.
2. A head and posterior end.
3. A circulation analogous to that of the Infusoria.

This animal, as we may justly call it, since it takes in living protozoans and rejects their shells, has the power of moving in a particular direction, one end of the body always advancing first; which indicates the rudiments of a nervous and muscular power; and can swallow, digest and circulate its food. Whether it gives out nitrogen and absorbs oxygen or not is unknown. It reproduces by self-division, and some allied forms by the production of monad-like, flagellate spores.

The Amœba is a fresh-water form, living on the stems and

leaves of fresh-water plants. The late H. J. Clark, our most eminent microscopist, thus describes its habits in his "Mind in Nature." "The three figures represent the various forms which I have seen the same individual assume, whilst I had it under the microscope, as it crept over the water-plants upon which it is accustomed to dwell. The most usual form which it assumed is that of an elongated oval (A), but from time to time the sides of its body would project either in the form of simple bulgings (B), or suddenly it would spread out from several parts of the body (C), as if it were falling apart; just as you must have seen a drop of water do on a dusty floor, or a drop of oil on the surface of water; and then again it retracted these transparent arms and became perfectly smooth and rounded, resembling a drop of slimy, mucous matter, such as is oftentimes seen about the stems of aquatic plants."

Pelomyxa (Fig. 134) is a fresh-water Amœba-like form, but provided with spicules. Under the name of *Amœba sabulosa* Prof. Leidy describes* a form which he thinks "is probably a member of the genus Pelomyxa," and which is characterized by the comparatively enormous quantity of quartzose sand which it swallows with its food. "The animal might be viewed as a bag of sand!" It is from one-eighth to three-eighths of a line in diameter, and was found on the muddy bottom of ponds in Pennsylvania and New Jersey. It is possibly *Pamphagus mutabilis*, figured by Professor Bailey in the "American Journal of Science and Arts," 1853. Another form resembling Greef's Pelomyxa, and found by Professor Leidy in a pond in New Jersey, is *Deinamœba mirabilis;*† its body bristles with minute spicules. He has also described in the same Proceedings (p. 88) *Gromia terricola*, which lives in the earth about the roots of mosses growing in the crevices of the bricks of the pavements of the streets of Philadelphia. He thus graphically describes this singular form. "Imagine an animal, like one of our autumnal spiders, stationed at the centre of its well spread net; imagine every thread of this net to be a living extension of the animal, elongating, branching, and becoming confluent so as to form a most intricate net; and imagine every thread to exhibit actively moving currents of a viscid liquid both outward and inward, carrying along particles of food and

*Proceedings of the Academy of Natural Sciences, Philadelphia, 1874. p. 86.
†l. c. p. 142.

dirt, and you have some idea of the general character of a Gromia."

A convenient division of the Rhizopods is into two groups, Foraminifera and Radiolaria. Schultze divides the former into :—

1. *Nuda*, or naked forms, such as Amœba and Actinophrys.

2. *Monothalamia*, forming a one-chambered shell, but with the animal undivided, living in the simple hollow of the shell. Fresh-water forms are Arcella, Difflugia and Gromia, while Cornuspira is a marine form.

3. *Polythalamia*, with many-chambered shells; all marine. The three divisions are represented by (1) Acervulina, (2) Nodosaria and (3) Miliola, Rotalina, Globigerina, Textularia, Nummulina, Polystomella, etc.

The Rhizopods are divided by Hæckel into 1. *Acyttaria*, or the one and many chambered Foraminifera; 2. The *Heliozoa*, represented by *Actinosphærium* (*Actinophrys*) *Eichhornii*, or sun-animalcule; and 3. The *Radiolaria*. These last two groups he divides (*a*) into the *Monocyttaria* (represented by Cyrtidosphæra, Thalassicolla and Acanthometra, etc.) and (*b*) the *Polycyttaria*, represented by Collozoum, Sphærozoum and Collosphæra. Hæckel, who has studied these Radiolaria more than any one else, though Johannes Müller gave us the first definite information about them, says that "in the lower forms they are allied to the sun-animalcules and Foraminifera, but the higher forms are much more highly developed. They differ from both the Actinophrys and Foraminifera, in that the central part of the body is made up of many cells, and is surrounded by a strong membrane. This closed, more or less spherical "central capsule" is surrounded by a slimy layer of protoplasm, from which thousands of very fine threads radiate, and often branch out and anastomose. Among them are scattered numerous yellow cells, which contain starch granules." (Whether these yellow cells are parasitic organisms, or belong to the animal, is not yet known.) Most Radiolaria are provided with a highly developed silicious frame-work, like the outer shell of a nest of Chinese carved balls, the outer surface of which is studded with spines; but both the form of the silicious box and the spines varies greatly, as may be seen by a glance at the plate in volume III* (after J. Müller), illustrating the Polycystina. Some Radio-

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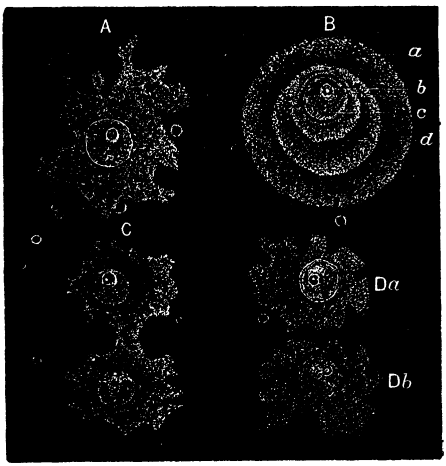
*Explanation of the plate. Fig. 1, *Tetrapyle octacantha*; Fig. 2, *Haliomma amphidiscus*; Fig. 3, *Haliomma longispinum*; Fig. 4, *Haliomma hexacanthum*; Fig. 5, *Haliomma*?

laria have a many chambered shell like those of the Polythalamia.

While the Foraminifera live mostly at the bottom of the sea (some, however, occurring between tide marks) on stones and seaweeds, creeping over sand and mud by means of their pseudopods, the marine Radiolaria for the most part float with outstretched pseudopods on the surface of the sea. They occur in countless numbers, but are usually so small that until 1858 they had been almost entirely overlooked by naturalists. The compound, or social forms, such as Collosphæra, are nearly an inch in diameter, while most of the simple species cannot be seen with the naked eye. The Polycystina occur fossil in abundance at Barbadoes, Richmond, Va., and the Nicobar islands.

Development. So far as is known Amœba multiplies its kind only by the simplest mode of reproduction known, that of self-division. The following figure (133), copied from Hæckel, represents

Fig. 133.



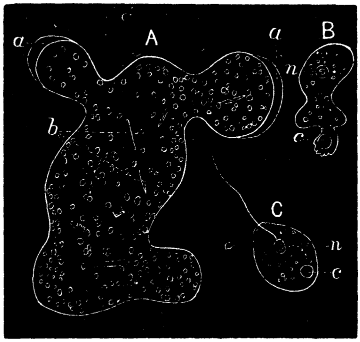
Amœba sphærococcus.

highly magnified, *Amœba sphærococcus*, a fresh-water species without a contractile vesicle, in the process of fission; at B is the encysted Amœba in its "resting stage." It now consists of a spherical lump of protoplasm (*d*), in which is a nucleus (*c*) with its nucleolus (*b*) and the whole surrounded by a cyst or cell-membrane (*a*). It breaks the cell-wall and becomes free as at

A. Self-division then begins as at C, the nucleus doubling itself, until at *Da* and *Db*, we have as a result two individuals.

In Pelomyxa, a higher form than Amœba, we have according to Greef a production of ciliated zoospores. This form, described by Greef under the name of *Pelomyxa palustris* (Fig. 134, A, *a*, clear portion ; *b* diatoms enclosed in the body mass), lives in the mud at the bottom of pools, and when first seen resembles little dark balls of mud ·04–·05 inch in diameter. The body mass contains numerous vacuoles filled with water, and numbers of nuclei and spicules. These nuclei and spicules have a dancing motion, like the ordinary Brownian movements of molecules. There are also numerous hyaline, oval or rounded bodies which Greef calls "shining bodies," and which originate from the nuclei. They increase by division within the body-mass of the Pelomyxa, becoming Amœba-like bodies (Fig. 134, B, *n* nucleus, *c* contractile vesicle) which issue in great numbers from the parent-mass. These Amœboid forms gradually pass into flagellate zoospores (Fig. 134, C) with a nucleus and contractile vesicle. It thus seems that the zoospores of this Rhizopod are produced without the animal becoming encysted.

Fig. 134.



Pelomyxa palustris.

As regards the development of Actinophrys and the allied spiny forms, Greef thinks that besides being formed by direct self-division, there is a resting or encysted stage. "The latter consists in the withdrawal of the sarcode body-mass from the inner boundary formed by the union of the bases of the radial spines, leaving a rather wide empty border, and its becoming invested by a double coat, viz., a firm inner one, when empty, dotted, as if perforated, and an outer hyaline one."

According to Schneider, *Actinophrys Eichhornii* undergoes division ; the central mass divides twice or thrice. Then the alveolar cortical layer disappears, and each mass resulting from the self-division becomes encysted. This process is undergone in two days. It remains encysted through the winter until the beginning

of May, when the cyst drops off and a small Actinophrys with a number of nuclei appears.

As an example of the reproduction of these forms by fission, we may cite the case of *Gromia socialis*, figured by Archer. He represents the body of a Gromia after having undergone a transverse self-fission, having in each portion a nucleus with its nucleolus, the upper segment giving off branched pseudopodia as usual.

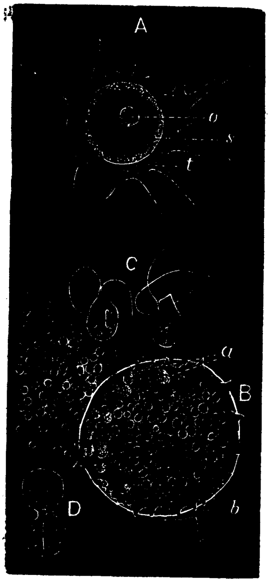
Of the mode of development of the shelled Amœbæ or Foraminifera (Polythalamia), numerous and often accessible as these animals are, we know but little. In fact, we have only the fragmentary observations of Max Schultze, made in 1856, on a species of Miliola sent him from Trieste. He says that this Foraminifer, after remaining from eight to fourteen days in the same place on the side of the jar, became surrounded with a thin layer of brownish mud, so that the shell was lost to view. On the 15th of May he noticed that small, round, sharply defined bodies escaped from the brownish slimy mass, and after some hours as many as forty such bodies surrounded the Miliola. These round bodies were young Foraminifera in calcareous shells with one turn, but no inner walls, somewhat resembling Cornuspira, and with pseudopodia already like those of the adult. It is probable, therefore, that the shell of the young is formed within the parent. Schultze adds that the almost complete want of organic contents in the shell of the parent at this time, rendered it probable that the whole or greater part of its body had passed into those of the young.

Of the mode of development of the Radiolaria, Prof. Cienkowski afforded, in 1871, the first definite information. He states that "J. Müller saw in the interior of an Acanthometra a swarming of small monad-like vesicles, which moved about for a time, and then changed themselves into Actinophrys-like structures. Afterwards," Hæckel saw, first, in Sphærozoids, "the contents of the capsules break up into many vesicles, and secondly, in Sphærozoum, he observed masses of vesicles which exhibited a vibratory movement." Lastly, Schneider had noticed in Thalassicolla groups of amœboid vesicles with movable flagellum-like processes. These facts rendered it probable, what Cienkowski has proved, that the Radiolaria reproduce by motile germs, *i.e.*, zoospores.

He studied the compound forms, such as Collosphæra and Collozoum, which are composed of aggregations of capsules (Fig. 135 A,

a capsule of a young Collosphæra without the latticed shell), held together by a common mass of protoplasm. These capsules are separated by a certain interval from one another, while the protoplasm binding them together consists of alveoli (vesicles) of various sizes, between and on to which sarcodic threads and networks are disposed. "I always found," he adds, "the capsules supported on the surface of the alveoli, often lenticular, compressed, and enclosed by a radiating layer of protoplasm, which also spreads itself over the alveoli, and passed over continuously into the sarcodic envelope of neighboring capsules. Besides those alveoli which carry capsules, there are many smaller, which are free from capsules."

Fig. 135.



Collosphæra.

Collosphæra spinosa (Fig. 135, B) possesses a fenestrated shell beset with small spines, which encloses a capsule with a protoplasmic investment. Fig. 135, B, *a*, indicates the problematical yellow cells. Fig. 135, A, indicates a young capsule of another spineless species, *C. Huxleyi* Müll. The young capsule of this species is naked, embedded, without any shell, in a radiated protoplasmic sheath, not emarginated by any sharply marked envelope. "In this stage they often divide themselves by fission into two halves. Not until maturer age does the capsule obtain a resisting membrane, and become enclosed in a fenestrated shell.

The next change which takes place in the capsule is its division into a number of little spheroids. This process is accomplished in a single day in *C. Huxleyi*. These spheroids become monad-like bodies, filling the capsule with a mass of corpuscles having a tremulous movement, and which finally swarm out in all directions (Fig. 135, B) from the capsule as true zoospores (C). The capsules now die and break up. These zoospores are provided with two long cilia. In the interior are a few oil drops, and a little crystalline rod, which sometimes projects out of the body.

"Among the swarms of swimming zoospores lay many motion-

less ones dispersed," continues Cienkowski. "They were round or angular, with drawn-out points," and one or more constrictions could be seen in them (Fig. 135, D). "Apparently they were developmental stages of the zoospores, obtained as they were in course of formation from the contents of the capsule." Cienkowski observed the same process in *Collozoum inerme*, thus substantiating his observations on Collosphæra.

In the Rhizopods, then, we know certainly two modes of reproduction :—

A. By self-division, as in Amœba.

B. By the production of zoospores, as in the Radiolaria.

In the latter the following phenomena take place :—

1. The capsule is filled with spheroids by a probable division of the contents of the capsule, as in the encysted stage of Moners and Gregarinida.

2. The "out-swarming" of zoospores.

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